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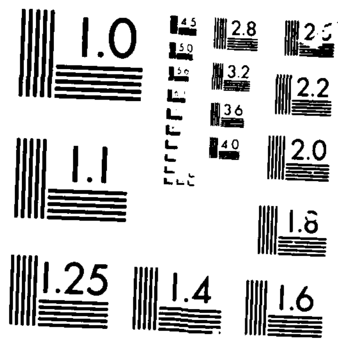

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COMPUTER SIMULATION OF THE DYNAMICS OF THE NEAR-EARTH PART OF THE GEOMAGNETIC TAIL

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5 May 1986

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The objective of the contract was to extend the Rice Convection Modeling capabilities tailward to include the near-Earth part of the geomagnetic tail, in order to include the dynamics of that region in our substorm simulations. The effort was divided into three parts: 1. Development of equilibrium magnetic-field models; 2. Development of an MHD code for use in the near magnetotail for periods when flows are supersonic or super-Alfvenic; 3. Modification of the Rice Convection Model to make it applicable further out in the magnetotail.

Development of equilibrium magnetic-field models. G. M. Erickson has developed an Alternating Directions Implicit method for solving the 2d magnetic-equilibrium equation $\nabla^2 A = -\mu_0\, dp/dA$. He used the method to construct a large number of equilibrium solutions for 2d magnetospheres. He has also constructed convection sequences of equilibrium models, to show how the magnetic-field configuration changes in time when a magnetotail is forced to convect earthward, adiabatically and losslessly. This convection induces two specific changes in the magnetic-field configuration: 1. steady increase in the strength of the magnetic field in the tail lobes; and 2. development of a deep minimum in magnetic-field strength in the center of the current sheet, near the earthward edge of the plasma sheet. These results clearly suggest answers to fundamental questions as to why magnetospheric substorms occur and what role they play in the overall dynamics of the magnetotail. His results also indicate why an x-line forms in the near-Earth part of the magnetotail, as indicated by the observations of Hones and others.

Development of an MHD code for use in the near magnetotail for periods when flows are supersonic or super-Alfvenic. L.-N. Hau has developed a two-dimensional two-step Lax-Wendroff resistive-MHD code for simulation of the dynamics of the near magnetotail. She has studied the development of the resistive tearing mode for various assumptions about the dependence of equatorial B_z with distance down the tail. When equatorial B_z, plotted as a function of distance down the tail, exhibits a deep minimum, as suggested by Erickson's quasi-static-equilibrium calculations, the tearing-mode x-line forms in the neighborhood of the deep minimum. A single plasmoid forms on the downtail side of the x-line and grows with time, in agreement with the observational substorm picture developed by Hones and others. The x-line forms much more quickly when the initial configuration has a deep minimum in equatorial B_z than when it does not. This work explicitly connects Erickson's mechanism for creation of a deep minimum in equatorial B_z with the formation of a plasmoid, and also suggests a qualitative explanation for the fact that a northward turning of the IMF frequently triggers a subtorm. Work continues toward a complete 2d theoretical representation of tail dynamics in a substorm.

Modification of the Rice Convection Model to make it applicable further out in the magnetotail. A complete new version of the Rice Convection Model has been developed by R. W. Spiro, G. A. Mantjoukis, and R. A. Wolf. This new code has many advantages over the old one, both in terms of more sophisticated numerical techniques, and in terms of physical processes included in the model. Some physical features that have been added to the model include thermospheric winds, magnetic-field-aligned electric fields, the equatorial electrojet, and the trapped-radiation belts. Improvements that were essential for use of the model further out in the tail included 1. a new algorithm for computing field-aligned currents from the magnetospheric plasma configuration, 2. a new potential solver that operates efficiently and accurately when used with a dense grid, and 3. a new algorithm that estimates the auroral enhancement of ionospheric conductance from local plasma-sheet properties and the density of Birkeland current. The new code has been extensively tested, and is now being used to study a number of physics problems that are central to understanding the ionosphere-magnetosphere system.

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I. INTRODUCTION

The Rice Convection Model has been developed over a long period of time (e.g., Wolf, 1970; Jaggi and Wolf, 1973; Harel and Wolf, 1976; Harel et al., 1981a; Spiro and Wolf, 1984). Following a general logical scheme formulated by Vasyliunas (1970), it uses certain input information (potential distribution at the polar-cap boundary, ionospheric-conductance model, magnetic-field model, plasma-sheet distribution function at the outer boundary of the model, initial magnetospheric plasma distribution) and computes ionospheric and magnetospheric electric fields, flow velocities, and currents, as well as the magnetospheric particle distribution. The modeling region is typically arranged to extend to a geocentric distance just slightly less than the magnetopause standoff distance at the subsolar point. Discussions of the formulation of the model have been given by Harel et al. (1981b), Spiro and Wolf (1984), and Wolf and Spiro (1985).

The convection model solves the basic large-scale-physics equations within its region of application, except for the following limitations:

1. In the momentum equations used to compute the drift motions of the various types of magnetospheric particles, the inertial term $m\, d\mathbf{V}_{drift}/dt$ is neglected compared to the magnetic-force term. This limits the applicability of the model to flows that are far below the fast-mode speed, and to time scales long compared to the MHD-wave travel time.

2. The magnetic-field is taken from an input model rather than being computed self-consistently. Consequently, the curl of the model magnetic field is not generally equal to $\mu_0\mathbf{J}$, where $\mathbf{J}$ is the current density computed by the convection model. This use of an inputted magnetic-field model profoundly simplifies the calculation: instead of doing a calculation in full 3d and time, we pursue two coupled time-dependent 2d calculations, one for the magnetosphere and one for the ionosphere.

However, these limitations have precluded reliable application of the Rice Convection Model to the magnetospheric tail. The magnetic-field model can be regarded as having reasonable accuracy only in the region where the Earth's dipole dominates $\mathbf{B}$.

The objective of this contract was to extend the Rice computer-modeling effort further out in the magnetotail, to include at least the middle plasma sheet, out to ~ 20-30 R_E geocentric distance, which requires inclusion the apparent heart of the substorm process. (Our previous substorm simulations (e.g., Harel et al., 1981a,b; Spiro et al., 1981) dealt with the reaction of the inner magnetosphere to the substorm process, not with the essence of the substorm phenomenon.) Preliminary work on the relation between magnetotail magnetic structure and convection (Erickson and Wolf, 1980) had shown that convection is likely to have strong and dynamic effects on the magnetic structure of the near tail. Thus the extension to 20-30 R_E could not be accomplished by simple modification of existing magnetic-field models. Most of the time, the portion of the plasma sheet that lies on field lines that close within about 30 R_E contains plasma that is flowing highly subsonically, in which case magnetic-equilibrium magnetic-field models could be used. However, very fast flows sometimes occur within 30 R_E. Specifically, magnetic reconnection is widely considered to occur within 30 R_E during substorms, and reconnection cannot be correctly represented by magnetic-equilibrium models.

At the outset of the project, it was clear that there were two possible computational approaches to the problem:

1. Try to build a full dynamic model of the 3d region, including the connection to the ionosphere, using an MHD code coupled to a realistic ionosphere.
2. Make some physical approximations, and do computer simulations of a simpler system in order to investigate the essential physics.

We decided on approach #2, partly because we felt that the 3d-and-time calculations required for approach #1 were not technically feasible yet, given the wide range of length scales and Alfven speeds involved in the problem, and partly because we feared that the 3d-and-time calculations would be so complex that it might be difficult to discern the essential physics from the computer results. We therefore chose to do several simpler 2d calculations first, making some physical approximations, with the hope that these calculations would supply a first theoretical picture of what happens in a substorm, though, of course, we knew that the 2d calculations could not possibly represent all of the essential physics of a substorm.

We simultaneously pursued three lines of attack. First (Section IIA), we calculated sequences of 2d quasi-static equilibrium magnetic-field models, to see the dynamic effects of convection on the magnetotail magnetic-field configuration. Second (Section IIB), we developed a resistive 2d MHD code to apply to the near magnetotail, for the purpose of representing the action of the tearing mode and plasmoid formation during substorm expansion phases. Third (Section IIC), we constructed a complete new Rice Convection Model, including improvements that would make it capable of including the near magnetotail, given an appropriate representation of the magnetic field in that region. A few smaller related theoretical projects were also carried out with partial support from this contract, and these are discussed briefly in Section IID. Section IIE provides some overall summary comments.

This final report summarizes the research effort two ways: Section II is a brief exposition of the essential results of the work, while Section III gives a chronological recapitulation of the effort, based on the quarterly reports.

II. DESCRIPTION OF WORK

A. Development of Equilibrium Magnetic-Field Models.

The contract has supported a great deal of work on equilibrium magnetic-field models. We will summarize the work only briefly here, since it has already been written up in several forms, including a published preliminary report (Erickson, 1984) and a Ph.D. thesis (Erickson, 1985); a major paper, intended for the Journal of Geophysical Research, is essentially complete and will be submitted to the Air Force at the end of the contract.

Erickson developed a flexible numerical procedure for solving the equation of two-dimensional magnetohydrostatic equilibrium

$$\nabla^2 A = -\mu_0 \, dp/dA \tag{1}$$

where the magnetic field is given by

$$\mathbf{B} = \boldsymbol{\nabla} \times (A(x,z)\,\mathbf{e_y}) \tag{2}$$

and $\mathbf{e_y}$ is a unit vector in the y-direction. The vector-potential function A and the pressure p are both constant along magnetic field lines, so that p can be regarded as a function of A in (1).

Equation (1), an inhomogeneous elliptical equation in two dimensions, is solved by an alternating-directions-implicit method. The modeling region, and a sample computed magnetic-field configuration are shown in Figure 1. The boundaries of the region are the magnetopause, the equatorial plane, and a cut across the far tail at $x \approx -60\ R_E$. The vector-potential function A is usually set equal to a constant on the magnetopause. The function A is specified on the far-tail boundary. The pressure is specified at the back boundary in such a way as to be consistent with one-dimensional force balance. The pressure is also specified in the equatorial plane.

In addition to calculating a variety of static magnetic-field configurations, Erickson has also computed a number of convection sequences of magnetic-field configurations. In each case, he started from a smooth, nominal magnetic-field configuration, with B_z directed northward (upward) across the equatorial plane (x-axis). He then "evolved" the model by forcing it to convect. Specifically, he took a flux tube from just inside the dayside magnetopause, and laid it back on the tail lobe, then recomputed the magnetic-field configuration. For the closed-field-line region, he assumed that

$$p V^{\gamma} = \text{constant for a given flux tube} \qquad (3)$$

where $V = \int ds/B$ is the volume of a flux tube with one unit of magnetic flux. Sequences of these models were computed, with each successive model in a sequence having been subjected to more convection than its predecessor. In constructing the sequences, Erickson assumed that the plasma was frozen to the field lines.

The convection sequences consisted of two-dimensional models, for simplicity. However, one essential three-dimensional effect was patched into the calculation, namely the tendency of plasma-sheet plasma near the inner edge to flow sideways, perpendicular to the Earth-Sun line. In a strictly two-dimensional model, plasma-sheet plasma, subjected to steady sunward convection for a long time, would have to flow right into the Earth. In the real three-dimensional case, gradient/curvature drifts, the Earth's rotation, and the shielding of the inner magnetosphere by the inner edge of the plasma sheet all encourage plasma-sheet particles to flow around the inner magnetosphere rather than into it. The tendency of plasma-sheet particles to drift in the $\pm y$ direction as they approach the inner edge was patched into the 2d calculation by assuming that the flux tubes flow in a channel of variable width in the y-direction, and by letting the width increase sharply as the flow approaches the inner edge.

The effects of lossless adiabatic convection on the magnetotail magnetic configuration were found to be the following:

1. The magnetic field in the tail lobe increases monotonically as convection proceeds.
2. A deep minimum in equatorial magnetic field develops in the inner plasma sheet, a few Earth radii tailward of the inner edge. The minimum gets deeper and deeper as the convection proceeds, until the numerical scheme is unable to find a solution.

3. As the minimum develops, plasma continues to flow earthward through it.

The steady increase of field strength in the tail lobe as convection proceeds is, of course, consistent with observations in the growth phase of a substorm (e.g., Caan et al., 1975). The development of the minimum in equatorial field strength suggests neutral-line formation, as in the standard Hones (1984) substorm scenario.

The fact that Erickson's convecting magnetotail did not reach a steady-state solution was not surprising, of course. Our earlier work (Erickson and Wolf, 1980) and also corresponding work by Schindler and Birn (1982) had indicated the probable nonexistence of steady-convection solutions in the magnetotail.

In a separate research effort from Erickson's, G.-H. Voigt and G. Ye have been working to develop a code for computing magnetic-equilibrium configurations that is easily adaptable to three dimensions. (Erickson's method, based on the equation $\nabla^2 A = - \mu_0\, dp/dA$, does not carry over to 3d in a simple, natural way.) Their equilibrium code, a friction-type code, is based on an idea orginally proposed by Chodura and Schlüter (1981). Voigt and Ye have had some success with this friction code, but it still has numerical difficulties in the high-magnetic-field region near the Earth.

B. Development of an MHD Code for Use in the Near Magnetotail for Periods when Flows are Supersonic or Super-Alfvenic

Lin-Ni Hau has developed a two-dimensional 2-step Lax-Wendroff resistive-MHD code, for application to the near magnetotail. Her modeling region was a rectangular box, with earthward (left) edge at $x \sim -5\ R_E$, top edge at $z \sim 15\ R_E$, tailward (right) boundary at $x \sim -40\ R_E$, and bottom at the equatorial plane ($z=0$). A zero-flow boundary condition was assumed at the left, top, and right boundaries. Appropriate symmetry conditions were assumed at the bottom. For her initial condition, she used an analytic magnetic-field configuration of a type used by Birn (1980), solutions that are in force balance in the asymptotic limit ($L_z/L_x \to 0$, $|B_z|/|B_x| \to 0$). Choosing a model with small but finite ratios L_z/L_x and $|B_z|/|B_x|$, she ran the MHD code with zero resistivity, but with an extra friction term, to bring the almost-force-balanced analytic model closer to exact force balance. Once the initial model seemed satisfactorily close to force balance, she turned the friction off, turned the resistivity on, and began the main part of the simulation, which was intended to investigate the effect of resistivity on the evolution of the system. The magnetic Reynolds number ($L\mu_0 V_A/\eta$) for the simulation was equal to 500, for L chosen to be 2.5 R_E, the half-thickness of the plasma sheet.

In a test case similar to one run by Birn (1980), in which there was initially a small northward magnetic-field component at the lower boundary and this northward component declined smoothly and monotonically down the tail, she found that an x-line eventually developed, along with a single plasmoid. Her results were in good agreement with those obtained by Birn (1980) for the same initial configuration, though using a different numerical method.

When a similar simulation was run for the case where the initial magnetic-field configuration had a small, positive B_{ze}, but exhibited a deep minimum in B_{ze} in the inner plasma sheet instead of monotonically decreasing tailward, an x line also formed, but with two important differences:

1. The x-line now formed very near the initial minimum in B_{ze};
2. The x-line now formed much more quickly.

As in Birn's (1980) case, a single plasmoid forms tailward of the x. Figure 2 displays the plasmoid after a time equal to approximately twice the Alfven-wave travel time across the modeling region.

The initial configuration adopted here, with a deep minimum in B_{ze} in the near-Earth plasma sheet, was, of course, suggested by Erickson's results. It represented the physical situation where convection had proceeded far enough to create a deep minimum in B_{ze}, and then stopped. It was intended to correspond to the situation where the IMF turns northward after a substantial period of southward orientation, but before a substorm occurs. (A sudden northward turning of the IMF after a period of southward orientation is frequently observed to trigger substorm expansion-phase activity (e.g., Rostoker, 1983).)

Hau's calculations thus explicitly tied Erickson's essential result -- the formation of a deep minimum in B_{ze} as the essential result of adiabatic earthward convection -- to the formation of an x-line and single large plasmoid in the near magnetotail.

A full paper describing Hau's work is in preparation, and should be submitted to the Air Force at the end of the contract.

C. Modification of the Rice Convection Model to Make It Applicable Further Out in the Magnetotail.

One of our primary efforts over the last three years has been the design, development, and testing of a new version of the Rice Convection Model, a version which is a great improvement over its predecessors, both in numerical accuracy and in physical features included. The new model is a powerful tool for investigating the dynamics of the inner and middle magnetosphere, and its coupling to the ionosphere, and the neutral thermosphere.

In order to take full advantage of the power of modern computers and to make the new model computationally capable of treating the near-Earth part of the magnetotail, we have made several major changes in the numerical techniques used in the RCM. These changes include:

1. The change to a denser numerical grid, which allows more detailed treatment of both the auroral zone and the low and middle latitudes. As formulated, the grid is flexible, both with regard to the number and arrangement of grid points. Simulation of near-tail convection in a substorm will require a relatively dense grid in that region, due to the existence of sharp density gradients and complex and dynamic plasma configurations.
2. The adoption of a new and more accurate numerical technique to solve the elliptic differential equation for the ionospheric electric potential. This technique, developed by G. Mantjoukis and based on the Stabilized Error Vector Propagation method (Madala, 1978) has proved efficient, accurate, and reliable, even for relatively large number of grid points.
3. The inclusion of a new algorithm for calculating Birkeland current densities from the distribution of plasma in the plasma sheet. This algorithm can accurately treat even the very complex configurations of magnetospheric plasma that occur in substorms and in storm recovery phases. We had found that the old code's Birkeland-current algorithm was incapable of treating the near magnetotail with reasonable accuracy; this limitation was one of the major drivers behind our decision to develop the new code.
4. Reprogramming of the computer code to accept a variety of time-step algorithms. We can choose which time-stepper to use on the basis of

accuracy requirements and budgetary constraints for different applications of the program.

5. Adoption of a new point-moving algorithm. This algorithm is designed for the accurate treatment of the motion of even fast-drifting radiation belt particles and for inclusion of the effects of magnetospheric particle loss by precipitation and charge exchange.

The new version of the Rice Convection Model (see Figure 3) incorporates many physically significant features that were not included in earlier versions of the model. These new features are summarized below:

1. Self-consistent calculation of magnetic-field-aligned potential drops, electron precipitation, and ionospheric conductance. In previous versions of the RCM, magnetic-field-aligned electric fields were neglected, and, in most cases, the loss of plasma-sheet electrons by precipitation into the atmosphere was also neglected. The effects of auroral electrons on ionospheric conductance were estimated using an empirical statistical model, scaled by the AE-index. However, this statistical-model approach was clearly inadequate for treatment of coupling between the ionosphere and the near magnetotail in a substorm. A crucial aspect of this coupling is the enhancement of ionospheric conductance due to the enhanced auroral precipitation that occurs during substorm-associated collapse of midnight-region magnetic field lines. The new RCM attempts to take into account the effect of enhanced Birkeland currents, as well as enhanced plasma-sheet electron density and temperature, on electron precipitation, field-aligned potential drops, and ionospheric conductance. These quantities are now estimated in a self-consistent way (box labelled "Model of Field-Aligned Particle Motion" in Figure 3). We use model-computed quantities (Birkeland current density $J_{\parallel}$ and plasma sheet n_e and T_e) and follow the formulation of Knight (1973) to estimate the field-aligned potential drop, as well as the energy flux and average energy of precipitating electrons. We then use approximations (Spiro et al., 1982) to the results of Vickrey et al. (1981) to relate the computed energy flux and average energy of precipitating electrons to conductance enhancements in the auroral zone.

2. Magnetospheric effects of thermospheric winds. Thermospheric winds affect magnetospheric convection through the Ohm's law relation

$$\mathbf{J} = \boldsymbol{\sigma} \cdot \mathbf{E}' \tag{4}$$

where $\boldsymbol{\sigma}$ is the conductivity tensor, and $\mathbf{E}'$ is the electric field in the rest frame of the local neutral atmosphere. ($\mathbf{E}' = \mathbf{E} + \mathbf{v}_n \times \mathbf{B}$, where $\mathbf{v}_n$ is the neutral-wind velocity, relative to the rest frame of the solid Earth, and $\mathbf{E}$ is the electric field in that same rest frame.) The differential equation for ionospheric current conservation then becomes:

$$\nabla \cdot (\Sigma \cdot \nabla V) = -J_{\parallel} + \nabla \cdot \{B \int ds\, [\boldsymbol{\sigma} \cdot (\mathbf{v}_n \times \mathbf{B})/B]\} \tag{5}$$

where Σ is the field-line integrated conductivity tensor, V is the electric potential in the rest frame of the solid Earth, and $J_{\parallel}$ is the total density of magnetic-field-aligned current into the ionosphere, including both northern and southern hemispheres. Neutral-wind information is now used as input to the Rice Convection Model, using computational machinery developed by G. A. Mantjoukis. Several runs have already been done using a single-mode analytic wind model (Tarpley, 1970a,b), and we are about to carry out the first run using a three-dimensional wind model generated by R. G. Roble's Thermospheric General Circulation Model.

3. The equatorial electrojet. The new RCM includes a model of the equatorial electrojet in its equatorward boundary condition, a realistic model of the equatorial electrojet. In contrast, earlier versions of the RCM allowed no current to flow across the equatorward boundary (located about 13° from the equator).

4. Inclusion of Van-Allen particles. The new code includes improved algorithms to follow the motion of rapidly drifting trapped-radiation-belt particles. The program now self-consistently calculates the Birkeland currents generated by these particles and the effects of these currents on the electric-field distribution.

5. Ion loss. Neglect of ion loss processes in previous versions of the RCM prevented us from accurately representing the recovery phase of a magnetic storm, or even the end of the main phase. The new version of the code includes provisions for including ion loss by charge exchange and by precipitation into the neutral atmosphere.

The reformulation of the Rice Convection Model described above, including evaluation and testing of versions with different numerical methods and finally the writing and accuracy-testing of the complete new program (about 4000 lines of code), was a major undertaking and occupied a significant fraction of our time for the last three years. However, this large task is essentially completed. The new code is running and has been used successfully for a few physics runs already. All of the new features of the code are tested and operating, except for particle loss, which has been programmed but will not be activated until we gain some additional experience with other features of the new code.

D. Other Related Work.

Karty et al. (1984) used the old Rice Convection Model, as well as qualitative and analytic arguments to assess the possibility of generation of substantial region-one Birkeland current by gradient/curvature-drift currents in the sunward-flowing region of the plasma sheet. It was concluded that cross-tail gradients in the plasma content of plasma-sheet flux tubes can cause significant region-one currents. Definitive quantitative treatment of this process was not possible with the old convection model, because of limitations of the algorithm for computing Birkeland currents in the code and an inadequate density of grid points. This study will, however, be carried further with the new code.

The old Rice Convection Model was used to investigate the role of induction electric fields in the substorm-associated injection of plasma into the ring current. Several computer-experiment runs were made through an imaginary isolated substorm. In some runs, the magnetotail magnetic-field configuration was assumed to become very stretched and tail-like in the "growth phase" of the substorm, with subsequent collapse to dipolar form near midnight at the onset of the expansion phase. In some runs, plasma content was assumed to decrease markedly on the collapsing midnight-region flux tubes. The results indicated that the growth-phase stretching of the tail, the expansion-phase collapse, and the midnight-region depletion all substantially affected the ring current. However, the collapse-associated induction electric field was not found to be a globally dominant factor: ring-current injection also occurred in cases where the magnetic field was not assumed to collapse in the expansion phase. Although we were confident about these general physical conclusions, we regarded these runs as having marginal numerical accuracy, due to the relatively large grid size used in the old code and the inaccuracies in the computation of Birkeland currents.

Voigt and Wolf (1985) carried out a theoretical study of C.-C. Wu's hypothesis that the polar cusp is swept back away from the Sun, a configuration that occurs in his global-MHD simulations when the model IMF is northward. Equilibrium magnetic-field calculations by Voigt suggested that the swept-back cusp could only occur if the plasma pressure were quite high on closed field lines just inside the dayside magnetopause. Wolf compared rough theoretical estimates of the pV^{δ} values that would be required to create a swept-back cusp with those in a realistic plasma sheet and concluded that swept-back-cusp flux tubes probably could not be created by adiabatic convection of flux tubes from the nightside plasma sheet. However, Voigt and Wolf were unable to rule out diffusion through the dayside magnetopause as a mechanism for creating sufficient plasma pressure in cusp field lines. The debate with C.-C. Wu continues...

Wolf and Spiro (1984) compared electric-field and current patterns computed with the old Rice Convection Model for the March 22, 1979 (CDAW-6) magnetic storm with corresponding patterns computed by Y. Kamide and co-workers, and by V.M.Mishin and co-workers, using magnetogram-inversion techniques. Agreement was less than gratifying. Apparently, the model of ionospheric conductance is causing errors (of different kinds) in results from the two different modeling approaches. The results might also be taken as a suggestion that one assumption we normally make in applying the Rice Convection Model to specific events -- namely, that the potential at the high-latitude boundary of our calculation has a classic-convection form at times when there is a large potential across the polar cap -- is incorrect. However, Kamide and Richmond (private communication) have recently generalized their magnetogram-inversion algorithm to accept incoherent-backscatter-radar data as event-specific input, in addition to the ground magnetograms; this new algorithm seems to yield flow patterns that are much closer to classic convection.

Voigt (1986) presented a review of the theoretical methods that have been developed for computing magneto-hydrostatic magnetic-field configurations.

R. W. Spiro, G. A. Mantjoukis, and R. A. Wolf used the old Rice Convection Model to simulate a substorm-type event that occurred in the GISMOS incoherent-backscatter-radar campaign in January, 1984. Some preliminary comparisons were made with observations.

G. A. Mantjoukis, R. W. Spiro, and R. A. Wolf used the new Rice Convection Model to obtain a theoretical model of quiet-time wind-driven ionospheric electric fields, including, for the first time, the effects of quiet-time magnetospheric particle populations. This is essentially an effort toward an improved theory of Sq-currents and quiet-time ionospheric electric fields. The first simulations were done with an analytic Tarpley (1970a,b) wind pattern. We are pursuing this work in collaboration with A. D. Richmond and R. G. Roble of NCAR, using the much more sophisticated quiet-time wind patterns computed with Roble's Thermospheric General Circulation Model.

Voigt and Hilmer (1986) have carried out a theoretical analysis of the effects of a y-component of magnetic field on the structure of the Earth's magnetotail. Earlier statistical analyses of magnetic-field data from Earth's magnetotail revealed a positive correlation between the IMF B_y and magnetotail B_y components (Fairfield, 1979). Lui (1983) found a high degree of IMF-B_y penetration into the plasma sheet, and concluded that the IMF B_y is shielded less in the plasma sheet than in the tail lobe. Hannes Voigt and graduate student Robert Hilmer (not supported by this contract) offer a different interpretation: On the basis of the two-dimensional MHD equilibrium theory, they argue that the enhancement of B_y cannot be explained by partial penetration of the IMF. They developed a 2d tail model including a B_y-component and showed that the total B_y in the tail consists of an IMF-related vacuum background field and an additional field that exists only in the plasma sheet, owing to the shear of closed plasma-sheet field lines. The field-line shear is most likely caused by polar-cap convection, a conjecture that has been supported by Moses et al. (1985).

E. Summary Comments

Our three main lines of contract research have been highly successful. Erickson's equilibrium-modeling effort has, we think, convincingly demonstrated why magnetospheric substorms occur and what role they play in the magnetospheric-convection process. They also indicate why the basic substorm disruption occurs near the equatorial plane in the inner plasma sheet, rather than elsewhere. Lin-Ni Hau's calculations demonstrate that, within resistive MHD, the theoretically expected disruption is a single X-line in the inner plasma sheet, with a growing plasmoid on the tailward side. The new Rice Convection Model, developed in substantial part with support from this contract, is a powerful tool for studying the effect of the ionosphere on near-tail region, and the rest of the closed-field-line slow-flow region of the magnetosphere.

Two fundamental difficulties still remain with regard to our theoretical understanding of the near-tail region:

1. Our ignorance of the exact physical nature of the right side of the Ohm's-law relation

$$\mathbf{E} + \mathbf{v}\times\mathbf{B} = \mathbf{RHS}_? \qquad (6)$$

that allows reconnection to occur in the near magnetotail.

2. Lack of an efficient, flexible method for computing full 3d magnetic-equilbrium models of the magnetosphere, for computation of magnetic-field models that are self-consistent with the Rice Convection Model.

Neither of these problems seems very close to being solved.

The obvious next steps in this line of research would seem to be the following:

1. Sensitivity studies to determine how x-line formation in the near magnetotail depends on the exact nature of the form assumed for the right side of (6).

2. Development of a computational scheme for estimating time-dependent magnetic fields in the near magnetotail, for efficient coupling to the Rice Convection Model. These would not necessarily have to be in accurate force balance, point-by-point, but would embody the physical insights gained from the 2d modeling results of Erickson and Hau. Development of such a scheme would allow us to study the three-dimensional aspects of substorm dynamics, including the crucial coupling to the ionosphere.

III. RECAPITULATION OF THE WORK EFFORT

This section briefly recapitulates, in approximately chronological order, the individual steps in the contracted research, as described in the quarterly reports.

First Quarter

1. Gary Erickson constructed some two-dimensional force-balanced magnetosphere models.
2. Hannes Voigt began work programming an alternate scheme for magnetic-equilibrium models, based on balancing the net magnetic and pressure-gradient force with an artificial friction force that is proportional to the local velocity.
3. Janice Karty performed some computer experiments with the old Rice Convection Model that extended out into the near magnetotail and included some region-one Birkeland currents there.
4. George Mantjoukis began working on a new potential solver for the Rice Convection Model, a solver that would work efficiently and accurately when a large number of grid points is used.

Second Quarter

5. Gary Erickson worked on constructing convection sequences of magnetic-equilibrium models, particularly trying to find an automatic scheme for guessing the equatorial pressure in each successive member of the sequence.
6. Hannes Voigt continued work on the friction code, programming and debugging the scheme for computing the "time" derivatives.
7. Lin-Ni Hau joined the project and began examining the various standard MHD schemes that might be used for 2d modeling of the magnetotail.
8. Two papers were submitted for publication in the Magnetospheric Currents volume, one by Karty et al. concerning region-one currents flowing along plasma-sheet field lines in the near tail, and one by Spiro and Wolf reviewing recent research with the Rice Convection Model. An additional review paper, by Wolf and Spiro, was submitted to the proceedings of the

First International School for Space Simulations.

Third Quarter

9. Gary Erickson constructed his first convection sequence. The effect of particles drifting around the inner magnetosphere was represented, within these first models, by simply cutting the plasma-sheet pressure off at a constant maximum value. Magnetic pressure in the tail lobe increased as convection proceeded. After a sufficient amount of convection, a sharp minimum in equatorial B_z developed in the inner plasma sheet.

10. Lin-Ni Hau completed her comparison of MHD numerical schemes and chose the two-step Lax-Wendroff scheme as best suited to the near-tail-dynamics problem.

Fourth Quarter

11. Gary Erickson completed a second convection sequence, and reported results at the Los Alamos reconnection conference and the fall AGU meeting. A writeup was prepared for the proceedings of the reconnection conference.

12. Hannes Voigt found the crucial reference to the friction-code approach to computing magnetic equilibria in the controlled-fusion literature, namely the paper by Chodura and Schlüter (1981). He constructed the first fully converged equilibrium model of the magnetotail using the friction approach.

13. Bob Spiro and Dick Wolf carried out a series of computer experiments to study the role of the induction electric field in the injection of the storm-time ring current.

Fifth Quarter

14. Gary Erickson and Dick Wolf developed a scheme for representing, within the context of Erickson's sequences of two-dimensional equilibrium models, the effect of particles gradient-, curvature-, and **E×B**-drifting around the inner magnetosphere. The scheme involved assuming that the flux tubes drift sunward in a channel whose width in the y-direction increases toward the Earth, becoming infinite at the "shielding layer", which is essentially the inner edge of the plasma sheet.

15. Hannes Voigt completed some numerical accuracy and stability tests on the friction code.

16. Bob Spiro, George Mantjoukis, and Dick Wolf undertook a complete rewriting of the Rice Convection Model.

Sixth Quarter

17. Gary Erickson constructed a new convection sequence of equilibrium-magnetic-field models, this one using a variable-width channel to represent the effect of drift in the y-direction. The model showed a modest minimum in the equatorial B_z before the numerical scheme became unable to find further solutions.

18. Hannes Voigt and Dick Wolf began calculations aimed at physical understanding of C. C. Wu's swept-back polar cusp.

19. Bob Spiro, George Mantjoukis, and Dick Wolf continued work on the large task of developing a new Rice Convection Model.

20. Dick Wolf and Bob Spiro compared electric-field and current patterns obtained for the March 22, 1979 storm with the Rice Convection Model and with two magnetogram-inversion techniques.

Seventh Quarter

21. Gary Erickson continued to push his convection sequences, but had difficulty finding converged solutions beyond the stage of convection where a minimum in equatorial B_z formed.

22. Work was completed on the Voigt-Wolf theoretical study of C.-C. Wu's swept-back cusp, and a paper was submitted for publication in JGR.

23. Programming of Mantjoukis' new potential solver for the Rice Convection Model, based on the Stabilized Error Vector Propagation Method, was completed, and the routine passed its first test against a known analytic solution.

24. Bob Spiro's programming of the new Birkeland-current-calculation routine was completed, and testing begun.

25. Lin-Ni Hau completed testing of her two-step Lax-Wendroff code against known wave solutions. The code exhibited excellent accuracy and stability.

Eighth Quarter

26. Gary Erickson completed his first convection sequence with a realistic rounded magnetopause, and made substantial progress in his effort to push

his convection sequences further in time.

27. George Mantjoukis' new potential solver passed additional tests, showing excellent accuracy and acceptable efficiency. He continued to work improving details of the routine.

28. Testing was completed for the Birkeland-current calculating routine, after several modifications were made in the original scheme to improve accuracy.

29. A variety of time-step algorithms were tested for accuracy and efficiency. An economical scheme was developed for ensuring accurate treatment of fast-drifting trapped-radiation-belt particles, which could not be treated accurately by the old RCM.

30. Bob Spiro programmed and tested the main part of the particle-pushing routine.

31. Lin-Ni Hau successfully tested her MHD code against the tearing-mode solution obtained by Cross and Van Hoven (1971).

Ninth Quarter

32. Gary Erickson completed his Ph. D. thesis.

33. A new graduate student, Gang Ye, joined our group, to work with Hannes Voigt on development of the friction code.

34. George Mantjoukis began work on including the equatorial electrojet and thermospheric-wind effects in the Rice Convection Model.

35. Lin-Ni Hau began to do MHD simulations of the near magnetotail, using one of Gary Erickson's computed configurations as an initial condition.

36. Dick Wolf and Lin-Ni Hau developed an idea to explain the fact that a sudden northward turning, after a period of southward IMF, often triggers a substorm.

Tenth Quarter

37. Full-code tests were successfully made on all of the subroutines involved in the central logical loop of the Rice Convection Model (the central pentagon of Figure 3).

38. Formulation and programming was completed for the model of field-aligned particle motion and field-aligned potential drops, based on the model of Knight (1973).

39. George Mantjoukis completed and tested an algorithm for including the effect of the equatorial electrojet in the equatorward boundary condition.

40. A subtle accuracy problem was diagnosed in Lin-Ni Hau's MHD code, and work on a "fix" was undertaken.

41. Hannes Voigt wrote a major review paper describing the theoretical basis of magnetic-equilibrium models, based on his presentation at the Solar-Wind/Magnetosphere Coupling Conference earlier in the year.

Eleventh Quarter

42. Bob Spiro, George Mantjoukis, and Dick Wolf completed the first non-test simulation carried out with the new code with a realistic plasma and potential distribution. In addition to the physical features seen on runs with the old convection model, the dense grid used for this simulation allowed display of a clear example of rapid flow in the ionospheric-trough region, on the low-L side of the plasma sheet.

Twelfth Quarter

43. Gary Erickson completed a first draft of a major paper for publication in JGR.

44. George Mantjoukis completed programming to include a simple analytic model of the thermospheric winds in the new Rice Convection Model. A first simulation was carried out, representing an ideal quiet-time magnetosphere, driven only by winds, but including a realistic quiet-time particle population. The inner edge of the plasma sheet was found to have a substantial effect on the computed quiet-time electric-field distribution, particularly on the night side. (This work on quiet-time wind effects was not supported by this contract, but was mentioned here because of its extremely close relationship to contract work.)

45. Lin-Ni Hau continued to have difficulties using the resistive two-step Lax-Wendroff code to evolve Erickson's solutions forward in time. One basic difficulty was that the crucial minimum in equatorial B_z existed over only a few spaces on Erickson's grid. These solutions consequently were far from smooth in the crucial region. Unfortunately, the two-step Lax-Wendroff code was found to respond very poorly to a bumpy initial condition -- oscillations develop between the half-step and the full-step, and the solution is very

reluctant to settle down. Furthermore, Erickson's solutions did not provide a very rich set of initial conditions for the MHD simulations, and did not provide any really deep minima in equatorial B_z. The project was consequently reformulated into a study of the effect of a minimum in equatorial B_z on tearing-mode instability of a current sheet that has finite normal magnetic field. Analytic solutions of a form developed by Birn were used as initial conditions. This procedure provided a much richer set of initial conditions for a systematic MHD study of the tearing instability. It also allowed study of the effect of a minimum in equatorial B_z that is many grid spaces wide. Lin-Ni Hau began work on this reformulated problem.

46. Hannes Voigt developed an equilibrium theory for the effect of a magnetic B_y component on the magnetic structure of the plasma sheet and tail lobe, which provides an explanation for the observed fact that the y-component of the magnetic field is stronger in the plasma sheet than in the tail lobes. These ideas were presented at the Chapman Conference on Magnetotail Physics.

Thirteenth Quarter and to the End of the Contract

47. Gary Erickson is now nearly finished with his major JGR paper. It should be ready for submission by the end of the contract.

48. Lin-Ni Hau has successfully investigated the tearing-mode instability of a variety of magnetotail configurations, based on Birn-type analytic initial conditions. A deep minimum in the initial equatorial B_z was found to result in rapid formation of an x-line near the position of the initial minimum. A paper describing her results is in preparation, and should be ready for submission by the end of the contract.

49. Dick Wolf has drafted a brief paper that uses qualitative and simple analytic arguments to interpret and generalize the results obtained by Erickson and Hau, and discusses their relation to substorms. This paper should also be ready for submission by the end of the contract.

50. George Mantjoukis has almost completed the programming necessary to include Roble's Thermospheric General Circulation Model in the Rice Convection Model. He will carry out an extensive set of simulations, in an effort at a definitive study of the effects of the magnetosphere on the quiet-time ionospheric electric-field and current patterns. (This work on quiet-time wind effects is not supported by this contract, but is mentioned here because

of its extremely close relationship to contract work.)

51. Dr. M. Brio, a co-worker of C.-C. Wu at UCLA, has been hired temporarily, mainly to adapt a UCLA 2-d magnetic-equilibrium code for our use in modeling the near tail. The code has been successfully adapted to use with the type of boundary conditions specified in our approach, and work on increasing efficiency and spatial resolution is proceeding. We hope that this will be the answer to our search for an efficient and convenient scheme for computing magnetic equilibria in two dimensions.

52. Bob Spiro has completed programming for computing ionospheric conductivities from the Chiu 3d ionospheric model, and for including these 3d conductivities in the input machinery of the Rice Convection Model.

53. Kyoung Min has adapted the particle-in-cell MHD code of Lebouef, Tajima, and Dawson for application to the Earth's far magnetotail. He is now beginning to get physically interesting results. One primary objective of this study is to determine whether there exist physically reasonable stationary MHD solutions for flow in the far magnetotail. (This work is not supported principally by this contract, but is mentioned here because of its close relationship to contract research.)

IV. BUSINESS DATA

A. Contributing Scientists

M. Brio, Research Associate

G. M. Erickson, Graduate Student (-3/85) and Research Associate (3/85-)

L.-N. Hau, Graduate Student

R. Hilmer, Graduate Student

J. L. Karty, Research Associate

G. A. Mantjoukis, Graduate Student

K. W. Min, Research Associate

R. W. Spiro, Research Scientist

G.-H. Voigt, Associate Research Scientist

R. A. Wolf, Professor

G. Ye, Graduate Student

B. Previous and Related Contracts

F19628-77-C-0005	(10/01/76 - 02/01/80)
F19628-77-C-0012	(10/01/76 - 09/30/77)
F19628-78-C-0078	(10/01/77 - 09/30/78)
F19628-80-C-0009	(01/01/80 - 12/31/82)

C. Publications

Erickson, G. M., On the cause of X-line formation in the near-Earth plasma sheet: results of adiabatic convection of plasma-sheet plasma, in Magnetic Reconnection in Space and Laboratory Plasmas, ed. E. W. Hones, Jr., AGU, Washington, D. C., p. 296, 1984.

Erickson, G. M., Modeling of plasma-sheet convection: implications for substorms, Ph. D. thesis, Rice University, 1985.

Karty, J. L., R. A. Wolf, and R. W. Spiro, Region-one Birkeland currents connecting to sunward convecting flux tubes, in Magnetospheric Currents, ed. T. A. Potemra, AGU, Washington, D. C., p. 269, 1984.

Spiro, R. W., and R. A. Wolf, Electrodynamics of convection in the inner magnetosphere, in Magnetospheric Currents, ed. T. A. Potemra, AGU, Washington, D. C., p. 248, 1984.

Wolf, R. A., and R. W. Spiro, Ionosphere-magnetosphere coupling and convection, in Proc. Conf. Achievements of the IMS, ESA SP-217, p. 417, 1984.

Wolf, R. A., and R. W. Spiro, Particle behavior in the magnetosphere, in Computer Simulation of Space Plasmas, ed. T. Sato and H. Matsumoto, Terra Publishing Co., Tokyo, p. 227, 1985.

Voigt, G.-H., and R. A. Wolf, On the configuration of the polar cusps in Earth's magnetosphere, J. Geophys. Res., 90, 4046, 1985.

D. Papers Accepted for Publication

Voigt, G.-H., Magnetospheric equilibrium configurations and slow adiabatic convection, to be published in the proceedings of the Chapman Conference on Solar-Wind/Magnetosphere Coupling, ed. Y. Kamide and J. A. Slavin, 1986.

Voigt, G.-H., and R. Hilmer, The influence of the IMF B_y component on the Earth's magneto-hydrostatic magnetotail, to be published in the proceedings of the Chapman Conference on the Physics of the Magnetotail, ed. A. T. Y. Lui, 1986.

Wolf, R. A., S.-I. Akasofu, S. W. H. Cowley, R. L. McPherron, G. Rostoker, G. L. Siscoe, and B. U. Ö. Sonnerup, Coupling between the solar wind and the Earth's magnetosphere: Summary comments, to be published in the proceedings of the Chapman Conference on Solar-Wind/Magnetosphere Coupling, ed. Y. Kamide and J. A. Slavin, 1986. (This publication, a written version of a panel discussion chaired by R. Wolf, is closely related to contract research, but does directly report results of contract research.)

E. Papers to be Submitted for Publication

(The following three papers, which are nearly ready for submission for publication, will constitute the basic published reports on two major contract tasks, the development of equilibrium magnetic-field models and development of an MHD code for use in the near magnetotail. Copies are being submitted to the Air Force along with this report.)

Erickson, G. M., Effects of magnetospheric convection on the magnetic structure of the near magnetotail, 1. Adiabatic plasma-sheet convection, to be submitted to J. Geophys. Res., 1986.

Hau, L.-N., and R. A. Wolf, Effects of magnetospheric convection on the magnetic structure of the near magnetotail, 2. Spontaneous X-line formation, to be submitted to J. Geophys. Res., 1986.

Wolf, R. A., G. M. Erickson, L.-N. Hau, and G.-H. Voigt, Effects of magnetospheric convection on the magnetic structure of the near magnetotail, 3. Overview, to be submitted to J. Geophys. Res., 1986.

F. Papers Presented at Meetings

Karty, J. L., R. A. Wolf, and R. W. Spiro, Region one Birkeland currents connecting to sunward convecting flux tubes, contributed paper, Chapman Conference on Magnetospheric Currents, Irvington, VA, April, 1983.

Spiro, R. W., and R. A. Wolf, Electrodynamics of convection in the inner magnetosphere, invited paper, Chapman Conference on Magnetospheric Currents, Irvington, VA, April, 1983.

Wolf, R. A., Electrodynamics of magnetosphere-ionosphere coupling, invited paper, Gordon Conference in Space Plasma Physics, Plymouth, NH, June, 1983.

Wolf, R. A., Magnetosphere-ionosphere interactions, invited reporter review, IAGA meeting, Hamburg, August, 1983.

Spiro, R. W., and R. A. Wolf, Computer simulation of ring-current injection on March 22, 1979, invited paper, IAGA meeting, Hamburg, August, 1983.

Wolf, R. A., Convective transport of plasmasphere ions, invited paper, IAGA meeting, Hamburg, August, 1983.

Erickson, G. M., On the cause of X-line formation in the near-Earth plasma sheet: results of adiabatic convection of plasma-sheet plasma, contributed paper, Chapman Conference on Magnetic Reconnection, Los Alamos, October, 1983.

Erickson, G. M., Quasi-static convection of plasma-sheet flux tubes using self-consistent magnetospheric-magnetic-field models in two dimensions, Fall AGU Meeting, San Francisco, 1983.

Wolf, R. A., and R. W. Spiro, Particle trajectories from the magnetotail to the inner magnetosphere, invited paper, Fall AGU Meeting, San Francisco, 1983.

Wolf, R. A., Ionosphere-magnetosphere coupling and convection, invited

paper, COSPAR, Graz, June, 1984.

Wolf, R. A., Review of models and theories of coupling processes, invited paper, COSPAR, Graz, June, 1984.

Wolf, R. A., Theory of magnetospheric convection, invited paper, COSPAR, Graz, June, 1984.

Voigt, G.-H., Computer simulation of the quasi-static region of the Earth's magnetosphere, invited paper, 2nd International School on Space Simulations, Kapaa, Kauai, Hawaii, February, 1985.

Mantjoukis, G. A., Electric fields at low ionospheric latitudes in numerical simulations of substorms, contributed paper, 2nd International School on Space Simulations, Kapaa, Kauai, Hawaii, February, 1985.

Erickson, G. M., Modeling of adiabatic convection in the Earth's plasma sheet: implications for magnetospheric substorms, contributed paper, 2nd International School on Space Simulations, Kapaa, Kauai, Hawaii, February, 1985.

Wolf, R. A., Magnetospheric dynamics, invited paper, NASA/STTP Workshop, Los Alamos, November, 1984.

Voigt, G.-H., Magnetospheric equilibrium configurations and slow adiabatic convection, invited paper, Chapman Conference on Solar-Wind/Magnetosphere Coupling, Pasadena, February, 1985.

Voigt, G.-H., and R. A. Wolf, On the configuration of the polar cusps in Earth's magnetosphere, contributed paper, Spring AGU meeting, Baltimore, May, 1985.

Wolf, R. A., and R. W. Spiro, The quiet magnetosphere -- a theoretical view, invited paper, IAGA meeting, Prague, August, 1985.

Spiro, R. W., R. A. Wolf, and G. A. Mantjoukis, An improved model of convection in the inner magnetosphere, contributed paper, IAGA meeting, Prague, August, 1985.

Wolf, R. A., Magnetospheric controls of ionospheric processes and critical parameters for predictability, invited paper, SUNDIAL workshop, MacLean, VA, September, 1985.

Voigt, G.-H., The influence of the IMF-B_y component on the magneto-hydrostatic magnetotail, Chapman Conference on Magnetotail Physics, Laurel, MD, October, 1985.

Erickson, G. M., Modeling of plasma sheet convection: implications for

substorms, Chapman Conference on Magnetotail Physics, Laurel, MD, October, 1985.

Wolf, R. A. The effect of the conducting ionosphere on magnetospheric dynamics, invited paper, Fall AGU meeting, San Francisco, December, 1985.

Spiro, R. W., R. A. Wolf, and G. A. Mantjoukis, Application of the Rice Convection Model to a substorm period during the January, 1984 GISMOS campaign, invited paper, Fall AGU meeting, San Francisco, December, 1985.

Mantjoukis, G. A., R. W. Spiro, and R. A. Wolf, Effects of quiet-time neutral winds on the electrical coupling between the ionosphere and magnetosphere, contributed paper, Fall AGU meeting, San Francisco, December, 1985.

Wolf, R. A., How the SUNDIAL data can help in magnetospheric modeling, SUNDIAL workshop, La Jolla, March, 1986.

G. Travel Performed

(We list below the trips that were funded wholly or partially from contract F19628-83-K-0016.)

Mo/Yr	Person	Meeting	Location	Full or Partial?
4/83	J. L. Karty	Chapman Conference on Magnetospheric Currents	Irvington, VA	Full
6/83	R. A. Wolf	Gordon Conference on Space Plasma Physics	Plymouth, NH	Partial
8/83	G. M. Erickson	Discussions with AFGL and Boston College personnel	AFGL	Full
10/83	G. M. Erickson	Chapman Conference on Magnetic Reconnection	Los Alamos, NM	Full
12/83	G. M. Erickson	AGU Meeting	San Francisco	Full
8/84	R. A. Wolf	Chapman Conference on the Magnetospheric Polar Cap	Fairbanks, AK	Full
1/85	G.-H. Voigt & R. A. Wolf	Meetings with AFGL personnel, and four lectures	AFGL	Full
2/85	R. W. Spiro	2nd International School for Space Simulations	Kauai, Hawaii	Partial
2/85	G.-H. Voigt & R. A. Wolf	Chapman Conference on Solar-Wind/Mag. Coupling	Pasadena, CA	Partial
3/85	R. A. Wolf	Meetings with AFGL and Air Weather Serv. personnel	Omaha, NB	Full
6/85	R. A. Wolf	Workshop on DoD req'ts for space predictions	AFGL	Full
9/85	R. A. Wolf	CRRES team meating	Pala Alto, CA	Full
10/85	G. M. Erickson, L.-N. Hau, G. Ye	Chapman Conference on Magnetotail Physics	Laurel, MD	Partial
12/85	R. W. Spiro	AGU meeting	San Francisco	Partial
1/86	R. A. Wolf	CRRES Science Team Mtg.	Cape Canaveral	Full

H. Fiscal Information

All of the $302,836 allotted to the contract has been spent. The contract work is complete.

I. Cumulative Cost Data

(The "actual" figures listed below are estimates, based on the most recent University accounting data (up to March 31, 1986) and our estimated spending for the last part of the contract. Some of the figures may change by a few dollars before the final accounting.)

	Amount Planned	Actual
Labor Elements		
Principal Investigator (R. Wolf)	$ 46,920	$ 21,522
Co-Investigators (G.-H. Voigt, R. W. Spiro, P. H. Reiff)	62,442	59,099
Other Staff and Students	40,906	76,000
TOTAL LABOR	$150,268	$156,621
Expenses		
International Travel	$ 0	$ 0
Domestic Travel	6,600	9,137
Computing	36,000	22,500
Fringe Benefits	19,480	18,432
Other Expenses	8,700	11,418
TOTAL EXPENSES	$ 70,780	$ 61,487
Equipment	$ 0	$ 0
Overhead	$ 81,788	$ 84,728
GRAND TOTAL	$302,836	$302,836

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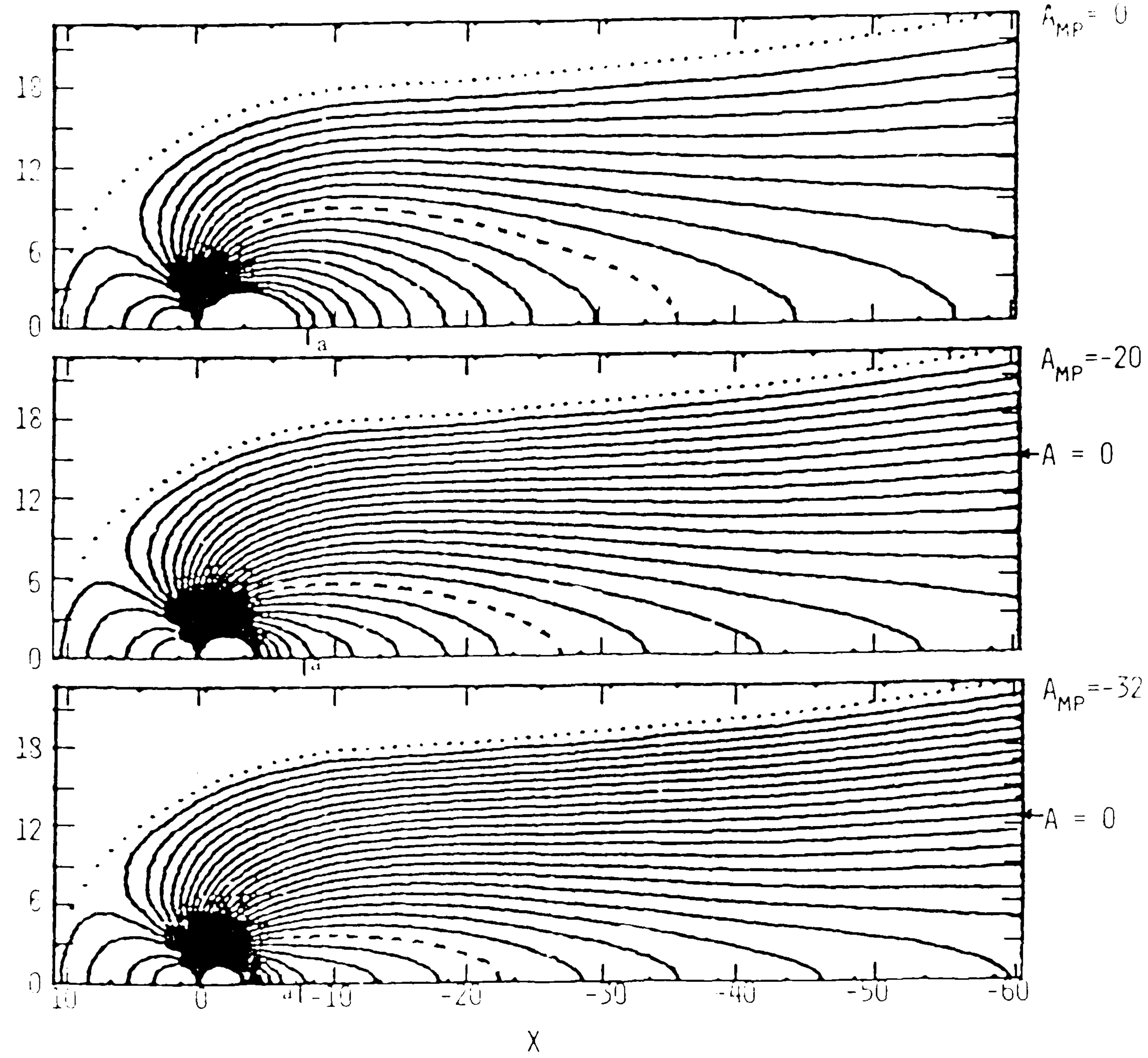
VI. FIGURE CAPTIONS AND FIGURES

Figure 1. Computed magnetic-field configurations shown for three different stages of convection. The top diagram represents the initial condition for the convection sequence. The middle and bottom boxes represent the results of adding 20 units of magnetic flux to the tail lobe, then another 12 units. The symbol "a" indicates the location of the shielding layer. The dashed field line indicates the location of one given flux tube (A=30) for each convection stage. From Erickson (1985).

Figure 2. Computed magnetic-field configurations for two stages in Lin-Ni Hau's resistive MHD calculation. The top box represents the initial condition, the bottom box the situation after approximately twice the time required for an Alfven wave to travel across the full length of the modeling region. The X-line formed at a time equal to about two-thirds of the Alfven-wave travel time across the full region.

Figure 3. Logic diagram for the new Rice Convection Model. The main calculations of the program are carried out in the central pentagon of the figure. The program goes around the central pentagon once every time step. Input models are represented by boxes with rounded corners. Light or dashed lines are used to indicate routines or connections that are not hooked up yet.



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$A = 0$
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6
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X
10
0
-10
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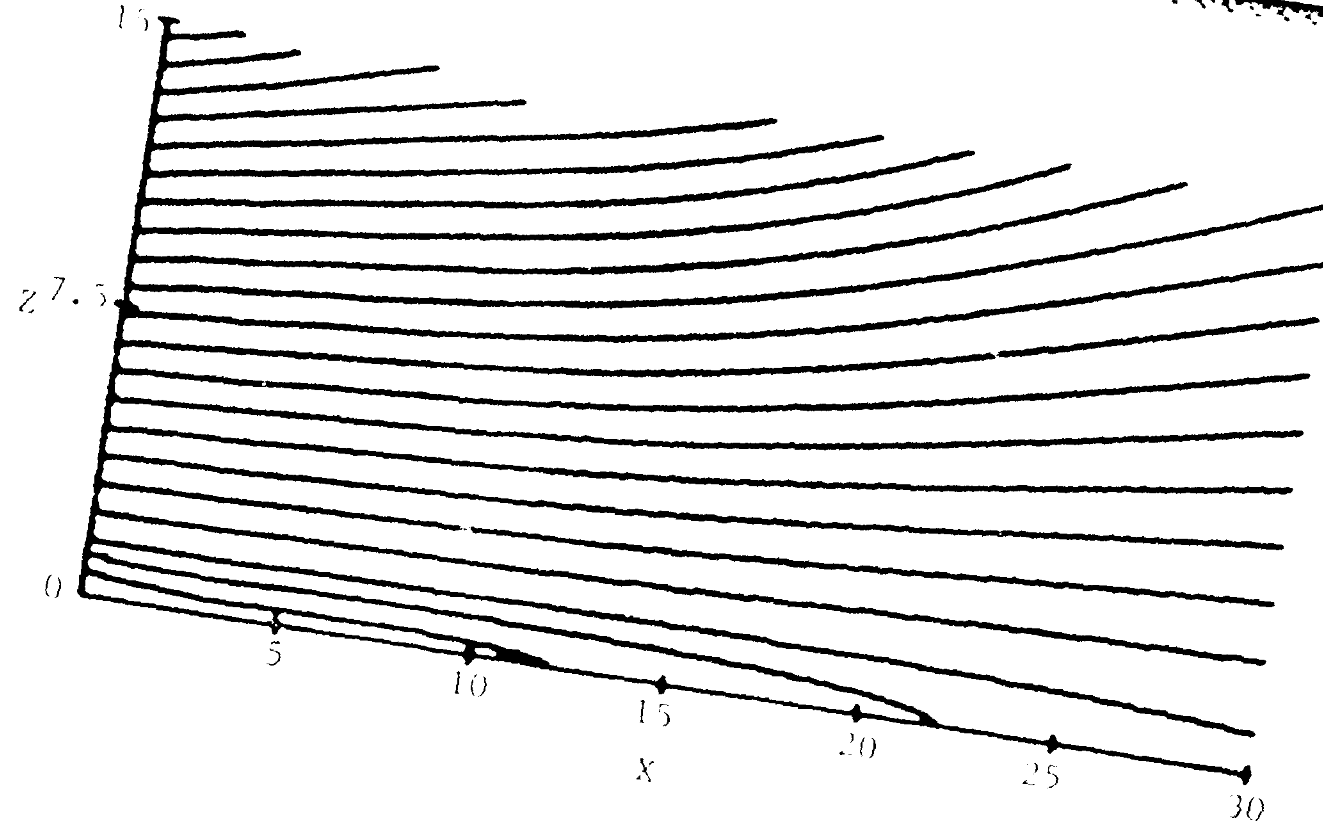
-30
-40
-50
-60
a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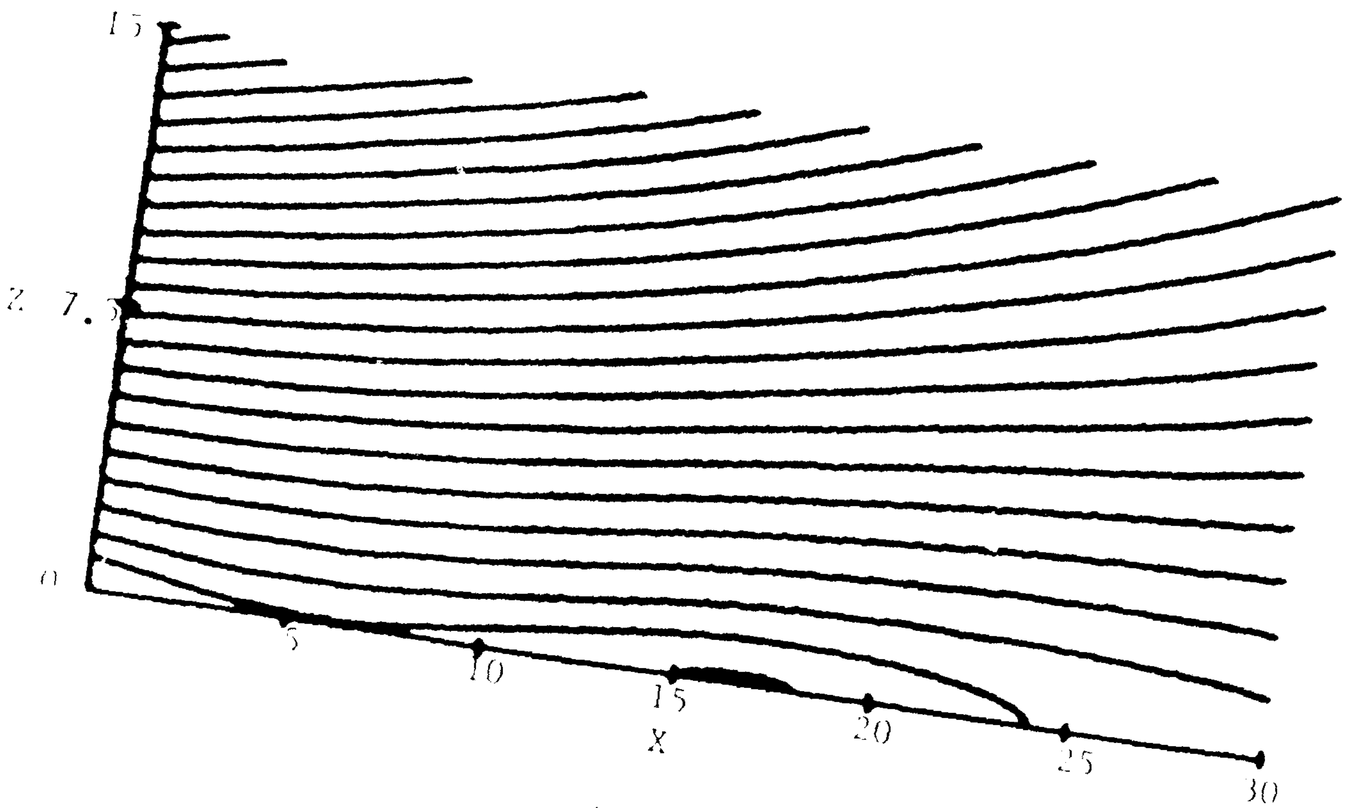
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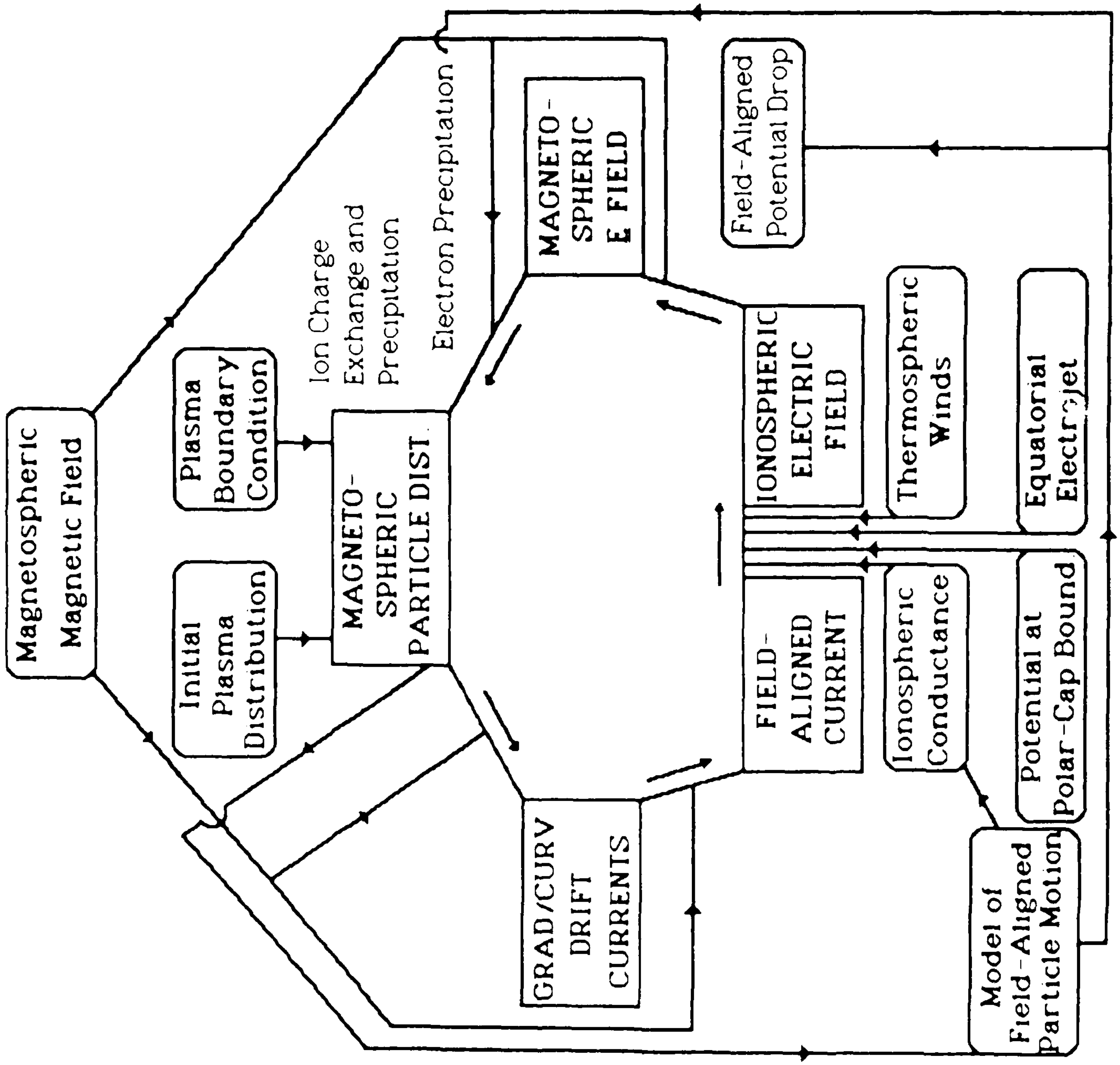
Magnetospheric Magnetic Field
Initial Plasma Distribution
Plasma Boundary Condition
MAGNETO-SPHERIC PARTICLE DIST.
Ion Charge Exchange and Precipitation
Electron Precipitation
MAGNETO-SPHERIC E FIELD
GRAD/CURV DRIFT CURRENTS
FIELD-ALIGNED CURRENT
IONOSPHERIC ELECTRIC FIELD
Field-Aligned Potential Drop
Thermospheric Winds
Ionospheric Conductance
Potential at Polar-Cap Bound
Model of Field-Aligned Particle Motion

END

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